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Gary L. Krapua
USGS Northern Prairie Wildlife Research Center, gkrapu@usgs.gov

David A. Brandt
United States Geological Survey, Northern Prairie Wildlife Research Center, dbrandt@usgs.gov

Deborah A. Buhl
United States Geological Survey, Northern Prairie Wildlife Research Center, dbuhl@usgs.gov

Gary W. Lingle
Platte River Whooping Crane Maintenance Trust

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GARY L. KRAPU[1], United States Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, ND 58401, USA

DAVID A. BRANDT, United States Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, ND 58401, USA

DEBORAH A. BUHL, United States Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, ND 58401, USA

GARY W. LINGLE[2], Platte River Whooping Crane Maintenance Trust, W. Whooping Crane Drive, Wood River, NE 68883, USA

Abstract: When an ice storm killed an estimated 2,000 sandhill cranes (*Grus canadensis*) in the Central Platte River Valley (CPRV) in Nebraska on 24 March 1996, we retrieved the fresh carcasses of 118 adults to test for a decline in the condition of spring-staging cranes from that date in 1978 and 1979. We first conducted a principle component analysis on 3 morphological variables (tarsus, exposed culmen, and wing chord [flattened]) and used the first principal component (PC1) as an index of body size. Then, to account for variation in body mass due to size, we regressed body mass on PC1 and computed an adjusted body mass using the residuals from this regression. For a sample of lesser sandhill cranes (*G. c. canadensis*) (n = 147) collected in 1978-79 and 1996, PC1 explained 63% of the total variation in body size and for greater sandhill cranes (*G. c. tabida*) (n = 75), 72% of variation. For both subspecies in 1978-79, the relationship between adjusted body mass and date depended on sex ($P < 0.08$) but not year ($P > 0.8$). For 24 March (the date of the ice storm in 1996), no significant differences in adjusted body mass were detected between 1978 and 1979 or between males and females for either subspecies. For lessers, the mean adjusted body masses for 1996 were 69-152 g less than the mean adjusted body masses predicted for 24 March 1978 and 1979; significant differences were detected only for males between 1996 and 1979 (difference = -152.5, SE = 75.9). For greaters, mean adjusted body masses for 24 March 1996 were 175-415 g less than the mean adjusted body masses predicted for 24 March 1978 and 1979; significant differences were detected only for females between 1996 and 1979 (difference = -415.1, SE = 126.5). In 1978 and 1979, adjusted body mass was correlated with total body fat. These results are not conclusive but do support the hypothesis that at least part of the sandhill crane population was carrying less fat on 24 March 1996 than on the same date in 1978 and 1979. Further studies are needed to gain greater insight into how fat storage patterns have been affected by declining waste corn in the CPRV and significance of this change to the midcontinental sandhill crane population.

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Key words: body mass, corn, condition, fat, *Grus canadensis*, ice storm, principal component analysis, mortality, sandhill crane

A major expansion in size of the foraging area used by the midcontinental population (MCP) of sandhill cranes (*Grus canadensis*) during their annual early spring stopover in the Central Platte River Valley (CPRV) of southcentral Nebraska occurred from the late 1970s to the 1990s. This led us to suspect that waste corn, the principal food of spring-staging sandhill cranes in the CPRV (Reinecke and Krapu 1986), may have declined, an assessment confirmed by later studies (Krapu et al. 2004). Also, we suspected that if waste corn had declined, the capacity of cranes to store fat may also have been reduced. A lower capacity to store fat would be significant as the CPRV is the principal spring staging area and fat storage site for the MCP of sandhill cranes (Krapu et al. 1985). Fat reserves acquired in the CPRV meet a significant part of the nutrient needs during spring migration and reproduction (Krapu et al. 1985). Therefore, when an ice storm struck the CPRV on 23-24 March 1996 and caused the death of at least two thousand sandhill cranes, we took measurements of freshly killed specimens to evaluate whether cranes carried less fat in the CPRV on 24 March 1996 than on the same date in 1978 and 1979. Specifically, our objectives were to: (1) compare predicted mean adjusted body masses for 24 March 1978-79 with mean adjusted body masses for the same date in 1996 by subspecies, sex, and year, and (2) determine whether amount of fat contained in a sandhill crane carcass is correlated with adjusted body mass.

STUDY AREA

The study was conducted in the CPRV of south-central Nebraska. Carcasses of sandhill cranes were retrieved after the ice storm within: (1) a 5-km radius of Ft. Kearney State Park in Buffalo County and (2) a 7-8 km radius of U.S. 281 and State Highway 11 in Hall County. Detailed descriptions of portions

[1] E-mail: gary_krapu@usgs.gov

[2] Present address: 7030 Kilgore Road, Gibbon, NE 68840 USA

of the CPRV used by sandhill cranes have been presented previously (U.S. Fish and Wildlife Service 1981, Krapu et al. 1982, Krapu et al. 1986).

METHODS

We classified sandhill cranes to subspecies based on their morphological measurements (Johnson and Stewart 1973). All were initially classified either as lesser sandhill cranes (*G. c. canadensis*), Canadian sandhill cranes (*G.c. rowani*) or greater sandhill cranes (*G. c. tabida*). *G. c. rowani* and *G. c. tabida* for our analyses were lumped into *G.c. tabida* based, in part, on recent information showing both to be the same subspecies based on their mitochrondrial DNA (Rhymer et al. 2001, Peterson et al. 2003).

Before evaluating differences in body masses among years, we accounted for variation in body masses due to individual variation in crane structural size, which was based on 3 morphological measurements: tarsus, exposed culmen, and wing chord (flattened). We used principal component analysis (PCA) to create a single variable describing structural size (Johnson and Wichern 1992). The PCA was performed separately for the two subspecies using PROC PRINCOMP of SAS (SAS 1999) with data from all three years. For each subspecies, we then regressed body mass on the first principal component (PC1) from the PCA and computed an adjusted body mass for each crane as [(observed mass - predicted mass from regression model) + mean mass for that subspecies]).

Analysis of covariance (ANCOVA) was used to examine relations between adjusted body masses, year, sex and collection date for the 1978-1979 data. A separate analysis was conducted for each subspecies. First, it was determined if a separate slope parameter for date was needed in the model for each sex and/or year (Milliken and Johnson 2002). Next, the resulting model was used to make comparisons between years and sexes and to predict the mean adjusted body mass for 24 March 1978 and 1979. Body mass predictions along with their associated standard errors and 95% confidence intervals were made for each sex and year combination.

A one-way analysis of variance (ANOVA) was used to examine the relationship between adjusted body mass and sex for the 1996 data. A separate analysis was conducted for each subspecies. Least squares means, standard errors, and 95% confidence intervals of adjusted body mass were computed for each sex. All ANCOVA and ANOVA models were computed using PROC MIXED of SAS (SAS 1999).

Differences in mean adjusted body mass for 24 March between 1996 and 1978-1979 were computed separately for each subspecies, sex, and year (i.e., 1978 and 1979). Standard errors and approximate 95% confidence intervals for these differences were also computed. To assess how well crane body mass correlates with amount of stored fat, we computed Pearson's correlation coefficients relating total fat to adjusted body mass for each subspecies, year, and sex combination. Total fat content of each crane was determined by Soxhlet extraction following Official Methods of Analysis (Horwitz 1975).

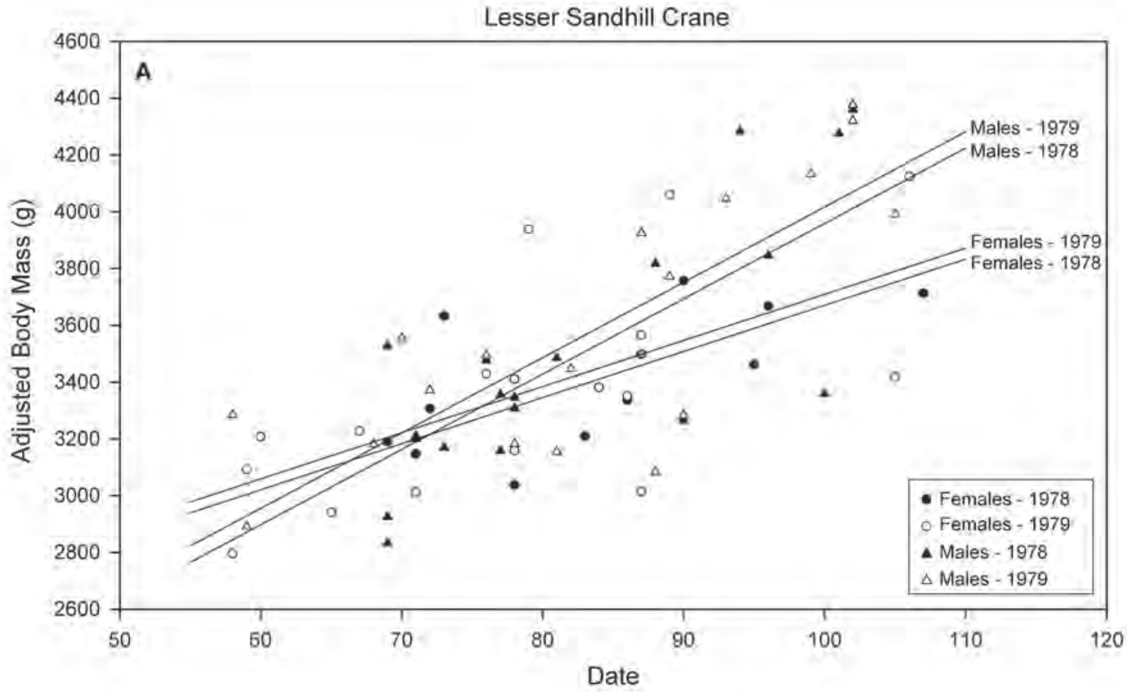
RESULTS

The first principal component (PC1) explained 63% of the total variation in the 3 morphological measurements for lesser sandhill cranes and 72% of the variation for greater sandhill cranes. There was a significant relationship between PC1 and body mass for both lesser sandhill cranes ($P < 0.01$) and greater sandhill cranes ($P < 0.01$).

For lesser sandhill cranes in 1978-1979, the relationship between adjusted body mass and date depended on sex ($P = 0.05$) but not year ($P = 0.83$). The rate of increase in body mass of males with date was greater than the increase for females (males: slope = 26.54, SE = 3.52; females: slope = 16.25, SE = 3.88). Therefore, the final model included a different slope parameter for each sex (Fig. 1A). Separate intercept terms for each sex by year combination were included in the model so that separate estimates of adjusted body mass could be made for each combination. We did not detect significant differences in adjusted body mass between 1978 and 1979 for either males ($P = 0.52$) or females ($P = 0.72$). Differences in body masses between males and females depend on date; therefore, for this analysis, we compared sexes for 24 March (the date of interest in this analysis). Significant differences in adjusted body mass were not detected between males and females on this date for either year ($P > 0.15$).

For greater sandhill cranes in 1978-1979, the relationship between adjusted body mass and date depended on sex ($P = 0.08$) but not year ($P = 0.94$). The rate of increase in body mass of males with date was larger than the increase for females (males: slope = 23.45, SE = 7.60; females: slope = 5.68, SE = 6.32). Therefore, the final model included a different slope parameter for each sex (Fig. 1B). Separate intercept terms for each sex by year combination were included in the model so that separate estimates of adjusted body mass could be made for each combination. Significant differences were not detected between years for either females ($P = 0.17$) or males ($P = 0.93$). We did not detect significant differences between males and females on 24 March (the date of interest in this analysis) in either year ($P > 0.1$).

For the 1996 data, significant differences in mean adjusted body mass were not detected between males and females for either lesser sandhill cranes ($P = 0.13$) or greater sandhill cranes ($P = 0.70$). The mean adjusted body masses for female and male lesser sandhill cranes indicated broad overlap in all 3 years (Table 1, Fig. 2). Differences in mean adjusted body mass between 1996 and 1978 were -69.13 (SE = 89.89) for females and -94.83 (SE = 75.98) for males. Approximate 95% confidence intervals for the differences showed no significant differences in mean adjusted body mass between 1996 and 1978 for either males or females. Differences between 1996 and 1979 were -107.28 (SE = 75.51) for females and -152.46 (SE = 75.93) for



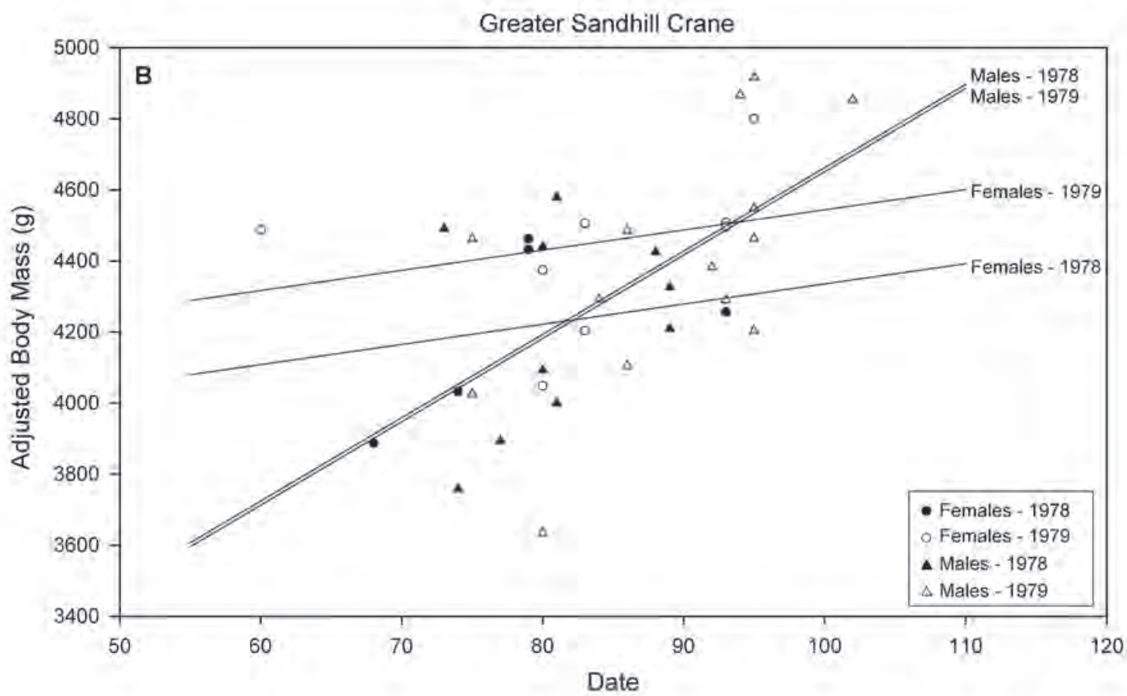


Fig. 1. Final model for adjusted body masses by date for each sex by year combination of adult male and female (A) lesser sandhill cranes and (B) greater sandhill cranes collected in the Central Platte River Valley, Nebraska, during late winter and spring 1978 and 1979.

Table 1. Predicted mean adjusted body masseș SE and 95% with confidence limits (in parentheses) for female and male lesser sandhill cranes (G. c. canadensis) and greater sandhill cranes (G. c. tabida) on 24 March 1978 and 1979 and mean adjusted body masses for these subspecies on 24 March 1996.

	Females			Males		
Subspecies	N	Mean ± SE	(95% CI)	N	Mean ±SE	(95% CI)
G. c. canadensis						
1978[a]	11	3394.2 ±82.0	(3230.2, 3558.2)	19	3507.5 ± 62.4	(3382.7, 3632.4)
1979[a]	18	3432.4 ± 65.9	(3300.5, 3564.2)	19	3565.2 ± 62.4	(3440.4, 3689.9)
1996	47	3325.1 ± 36.8	(3251.8, 3398.3)	34	3412.7 ± 43.3	(3326.6, 3498.8)
G. c. tabida						
1978[a]	5	4238.7 ± 120.3	(3993.7, 4483.7)	10	4263.4 ± 83.9	(4092.5, 4434.3)
1979[a]	9	4446.9 ± 88.4	(4266.9, 4626.8)	14	4252.2 ± 83.8	(4081.6, 4422.9)
1996	14	4031.7 ± 90.6	(3847.8, 4215.6)	23	4076.9 ± 70.7	(3933.4, 4220.4)

[a] For 1978 and 1979, the means and standard errors reported are the predicted mean adjusted body masses for 24 March and the standard errors of these predictions. All predictions were made from the ANCOVA models.

males. Significant differences were detected between 1996 and 1979 for males [confidence interval for difference was (-304.3, -0.59)] but not females.

For female greater sandhill cranes, the difference in mean adjusted body masses for 24 March 1996 and 24 March 1978 and 1979 were -206.98 (SE = 150.58) and -415.14 (SE = 126.54), respectively. Approximate 95% confidence intervals showed there was not a significant difference in mean adjusted body mass between 1996 and 1978, but there was a significant difference between 1996 and 1979 [confidence interval on difference was (-668.2, -162.1)]. For greater males, differences in mean adjusted body mass between 24 March 1996 and 1978 and 1979 were -186.51 (SE = 109.68) and -175.33 (SE = 109.61), respectively, with no significant differences between 1996 and 1978 or 1979. Adjusted body masses of both subspecies were correlated with total body lipids in the 1978/1979 sample of sandhill cranes (Table 2).

DISCUSSION

The marked increase in body masses of both subspecies of sandhill cranes while staging in the CPRV during 1978 and 1979 (Fig. 1A, B) occurred during a period when waste corn was abundant (Reinecke and Krapu 1986). The fact that predicted adjusted body masses on 24 March 1978 and 1979 were higher than mean adjusted body masses on 24 March 1996 in some year by sex combinations supports the hypothesis that the capacity to store fat may have declined in the CPRV. Also, body masses consistently averaged lower in 1996 for all sex and subspecies combinations when compared to 1978 and 1979 (Fig. 2), which, along with smaller standard errors in 1996, suggest small sample sizes in 1978 and 1979 may have contributed to lack of significance for some comparisons. Rates of increase in body masses of males during their spring stopover in the CPRV were higher than those of females in both 1978 and 1979 (Fig. 1). This difference was associated with males being larger than females and storing proportionately more fat (Krapu et al. 1985). The capacity of males to maintain a higher rate of fat storage than females despite their larger size and higher maintenance energy requirements reflects that waste corn was available in excess of needs (Reinecke and Krapu 1986).

An apparent reduced capacity of sandhill cranes to store fat in 1996 in the CPRV is not unexpected because several factors had resulted in less waste corn being available on the landscape in the CPRV by the late 1990s. These include increasing corn harvest efficiency, a major expansion in soybean production that replaced corn, and increased competition from arctic-nesting geese. Improvements in corn headers of combines and completing the switch from mechanical corn pickers to combines resulted in about half as much waste corn remaining on the ground post-harvest in Nebraska in the late 1990s as in the late 1970s (Krapu et al. 2004). In the 1970s, soybean fields were seldom encountered in the CPRV, but by 1996 soybeans were an important crop. Sandhill cranes avoided waste soybeans in spring in the CPRV (Krapu et al. 2004) so expanding soybean production resulted in less high energy food for cranes in the CPRV. Also, numbers of northern-nesting geese increased markedly in late winter and early spring in the CPRV from the 1970s to the 1990s causing a further reduction in amount of waste corn available to cranes in the 1990s (Krapu et

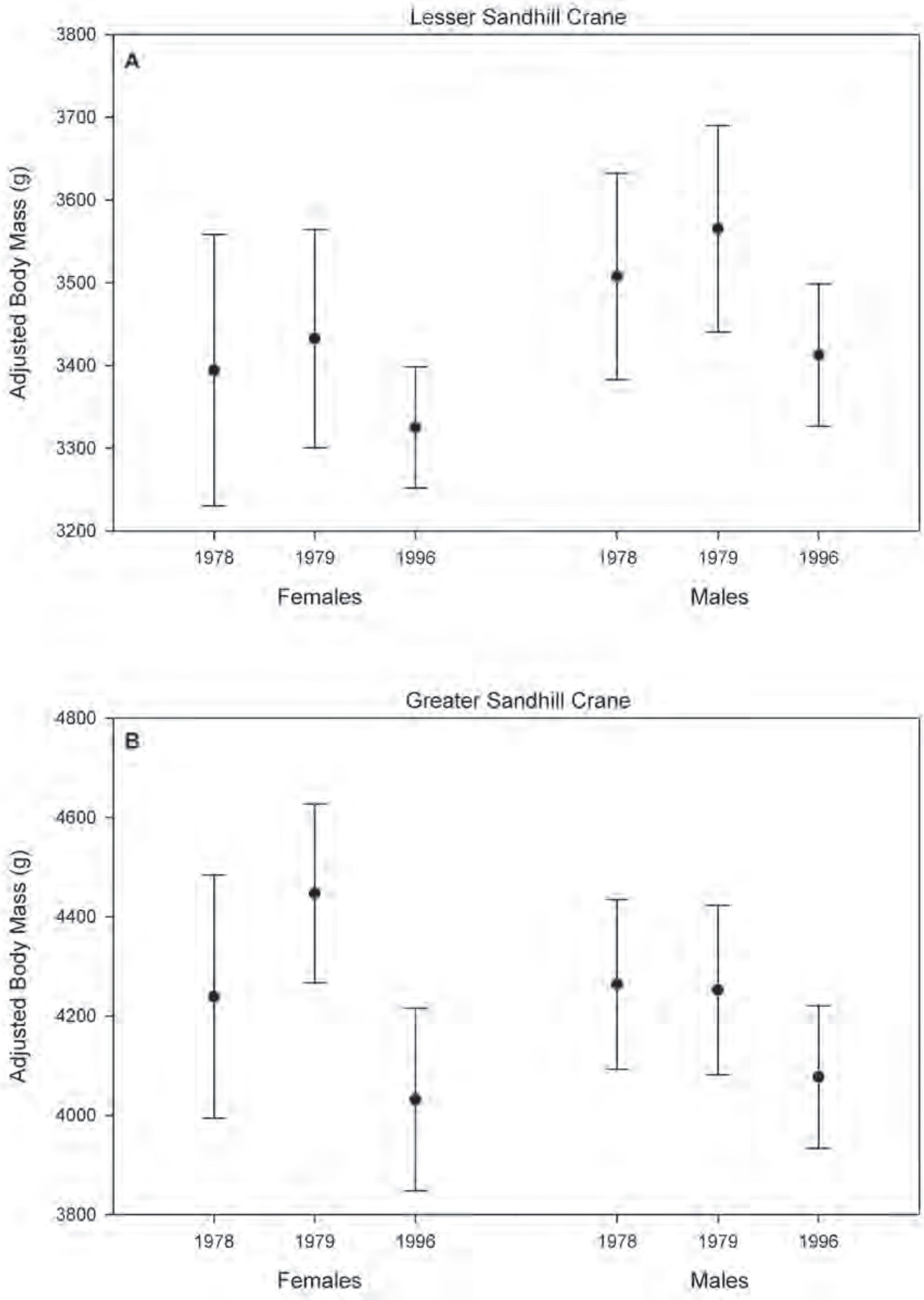


Fig. 2. Predicted mean adjusted body masses and 95% confidence intervals of adult male and female (A) lesser sandhill cranes and (B) greater sandhill cranes on 24 March 1978 and 1979 are compared to mean adjusted body masses and 95% confidence intervals on 24 March 1996 in the Central Platte River Valley, Nebraska.

Table 2. Pearson correlation coefficients are presented for relations between adjusted body masses and total lipids of sandhill cranes by subspecies and sex in 1978 and 1979.

		Year	
Subspecies	Sex	1978	1979
G. c. canadensis	F	0.749	0.843
	M	0.795	0.884
G. c. tabida	F	0.92 1	0.482
	M	0.363	0.737

al. 2005).

More efficient methods of harvest and weed control, along with expanded production of crops poorly suited for meeting crane nutritional requirements (Krapu et al. 2004), pose a long-term challenge for crane managers throughout the world. Baseline data is needed on condition of all crane species to provide crane researchers and managers with a sound means of detecting when the health of populations may be threatened by deteriorating habitat conditions. In the CPRV, evidence that fat storage has declined during the spring-staging period has alerted crane managers of the need to develop a long-term strategy to help ensure adequate food supplies remain available for cranes.

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